UNIVERSITI PUTRA MALAYSIA

PREDICTING SULPHUR DIOXIDE DISPERSION ISOPLETHS FROM MULTIPLE INDUSTRIAL SOURCES IN SEBERANG PERAI USING THE STEADY STATE GAUSSIAN PLUME MODEL

NURUL SULIANA BINTI AHMAD HAZMI

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By

NURUL SULIANA BINTI AHMAD HAZMI

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November 2006

To Mom and Dad, thanks for hanging in there through everything. I will never get this far without your support. To my brother and sister, thanks for always understanding and never-ending love.

And especially to all my friends, your help and encouragement have been so valuable to me. Hope the future holds something wonderful for all of you.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Associate Professor Ahmad Makmom Hj. Abdullah, PhD

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Air quality modeling is an essential tool for most air pollution studies and the introduction of SO_2 standards creates a need for modeling the dispersion of SO_2. This work deals specifically with the use of the Steady State Gaussian Plume Model at Seberang Perai Industrial Area, Penang. The study utilized air quality data which span over a period of 5years (1999-2003). The first objective of this study was to simulate SO_2 dispersion isopleths from multiple industrial sources at Seberang Perai Industrial Area which contributed to at least 70-75% of the total air pollution load in Penang. The second objective was to evaluate the Steady State Gaussian Plume Model by comparing the calculated and measured concentrations. The results showed that both simulated and measured concentrations are within a factor of 2, judged to be validated when the calculated and measured values do not differ in the annual averages by more than approximately 30% and the hourly concentration with 95% of the accumulative frequency distribution. Hence, Steady State Gaussian Plume Model employed by ISCST

(design by the U.S EPA) is verified and is suitable for simulating air pollutants dispersion from industrial activities in this country. The dispersion isopleths obtained in this study confer the first dispersion isopleths in Seberang Perai and formed a basis study for future scenarios that include the impacts of increasing energy consumption per capita, of changing populations and of new industrial development, including their optimal siting.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai keperluan untuk ijazah Master Sains

RAMALAN PENYEBARAN ISOPLET SULFUR DIOKSIDA DARI BERBILANG SUMBER INDUSTRI DI SEBERANG PERAI MENGGUNAKAN MODEL KEADAAN MANTAP PLUM GAUSSIAN

Oleh

NURUL SULIANA AHMAD HAZMI

November 2006

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Pemodelan kualiti udara adalah merupakan satu kaedah bagi kebanyakan kajian pencemaran udara dan kewujudan standard SO_2 menjadi faktor utama keperluan kepada pemodelan SO_2. Kajian ini di jalankan di Kawasan Perindustrian Seberang Perai, Pulau Pinang dengan menggunakan Model Keadaan Mantap Plum Gaussian bagi tempoh 5 tahun (1999-2003). Objektif pertama kajian adalah bagi menghasilkan penyebaran isoplet SO_2 dari pelbagai sumber industri di Kawasan Perindustrian Seberang Perai; yang menyumbang kepada 70-75% jumlah keseluruhan pencemaran udara di Pulau Pinang. Objektif kedua adalah bagi menilai Model Keadaan Mantap Plum Gaussian dengan membezakan kepekatan data simulasi dengan data kajian lapangan. Hasil kajian menunjukan perbezaan kedua-dua bacaan adalah di bawah faktor gandaan 2, yang mana disahkan benar apabila kepekatan data simulasi dengan data kajian lapangan tidak berbeza purata tahunannya dengan anggaran 30% dan kepekatan bacaan setiap jam

adalah 95% dari taburan frekuensi akumulatif. Oleh itu, Model Keadaan Mantap Plum Gaussian yang digunapakai dalam ISCST (direkabentuk oleh USEPA) juga adalah sesuai digunakan di negara ini bagi tujuan simulasi sebaran reruang bahan pencemar dari kawasan industri disamping dapat menjimatkan masa, menjangkakan kejadian yang tidak diingini serta dapat mengurangkan kos perlaksanaan operasi. Hasil kajian ini adalah yang pertama seumpamanya dalam penghasilan simulasi sebaran reruang bahan pencemar di Seberang Perai dan akan menjadi asas utama bagi kajian selanjutnya.

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I certify that an Examination Committee met on the 27th November 2006 to conduct the final examination of Nurul Suliana Binti Ahmad Hazmi on her Master of Science thesis entitled "Predicting Sulphur Dioxide Dispersion Isopleths From Multiple Industrial Sources in Seberang Perai Using the Steady State Gaussian Plume Model" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Act 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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Saya mengesahkan bahawa Jawatankuasa Peperiksaan Tesis bagi Nurul Suliana Binti Ahmad Hazmi telah mengadakan peperiksaan akhir pada 27 November 2006 untuk menilai tesis Master beliau yang bertajuk “Ramalan Penyebaran Isoplet Sulfur Dioksida Dari Berbilang Sumber Industri Di Seberang Perai Menggunakan Model Keadaan Mantap Plum Gaussian” mengikut Akta Universiti Pertanian Malaysia (Ijazah Lanjutan) 1980 dan Peraturan-peraturan Universiti Pertanian Malaysia (Ijazah Lanjutan) 1981. Jawatankuasa Peperiksaan Tesis memperakukan bahawa calon ini layak dianugerahi ijazah tersebut. Ahli Jawatankuasa Peperiksaan Tesis adalah seperti berikut:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotation and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NURUL SULIANA AHMAD HAZMI

Date: 22 FEBRUARY 2007

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Air Pollutant Index	API
Air Quality Monitoring Stations	AQMS
Alam Sekitar Malaysia	ASMA
Analysis of Variance	ANOVA
Business as Usual	BAU
Carbon monoxide	CO
Department of Environment	DOE
Environmental Protection Agency	EPA
Environmental Quality Act	EQA
Geographical Information System	GIS
Health Risk Assessment	HRA
Industrial Source Complex Short Term	ISCST
Institut Latihan Prai	ILP
Jabatan Ukur dan Pemetaan Malaysia	JUPEM
Kuala Lumpur International Airport	KLIA
Lead	Pb
Malaysia Air Quality Index	MAQI
Malaysia Meteorological Station	MMS
Nitrogen dioxide	NO_2
Non Government Organization	NGO
Ozone	O_3

Particulate matter	PM
Pollutant Standard Index	PSI
Recommended Malaysia Air Quality Guideline	RMAQG
Sulfur dioxide	SO_2
Suspended Particulate Matter	SPM
Total Suspended Particulate	TSP
United States of America	USA
United States Environmental Protection Agency	USEPA
Volatile organic compound	VOC
World Health Organization	WHO

CHAPTER 1

INTRODUCTION

Increasing air pollution levels due to rapid urbanization and growth in industrial emissions are now causes of major concern in many large cities of the world (Marsh and Foster, 1967; Martin and Barber, 1980; Katarina, 1993; Yadav and Kaushik, 1995; Jinliang et al., 2000; Ung et al., 2001; Desqueyroux et al., 2002; Manju et al., 2002; Bingheng et al., 2004; Graham, 2004; Yue et al., 2005; Panday et al., 2002, 2004, 2005; Filleul, 2005; Bhanarkar et al., 2005). When strategies to protect public health are under consideration, establishing ambient air quality standards and regulations have been introduced in order to set limits on the emissions of pollutants (United State Environmental Protection Agency, 1999). To achieve these limits, consideration was given to mathematical and computer modeling of air pollution. Therefore, air quality models are indispensable tools for assessing the impact of air pollutants on human health and the urban environment (Gokhale and Khare, 2004). The necessity for such models has increased tremendously especially with the rising interest in the early warning systems in order to have the opportunity to take emergent and preventive actions to reduce pollutants when conditions that encourage high concentrations are predicted (Perez, 2001). On the other hand, long-term forecasting and controlling of air pollution are also needed in order to prevent the situation from becoming worse in the long run. Such forecasting is especially important to sensitive group's i.e. children, asthmatics, pregnant women and elderly people (Tiitanen et al., 1999; Kolehmainen et al., 2001). The trend in recent years has been to use more statistical models instead of traditional deterministic models (Kolehmainen et al., 2001). The statistical models are based on semi-empirical relations among available data and measurements (Gokhale and Khare, 2004). They depend on the statistical analysis of previous air quality data and do not necessarily reveal any relation between cause and effect. They attempt to determine the underlying relationship between sets of input data and targets. They have been used to establish an empirical relationship between air pollutant concentrations and meteorological parameters (Gokhale and Khare, 2004). They are quite useful in real time short-term forecasting. Examples of statistical models are regression analysis (Abdul-Wahab et al., 1996, 2003, 2005) time-series analysis (Hsu, 1992) and artificial neural networks (Gardner and Dorling, 1998; Abdul-Wahab, 2001; Elkamel et al., 2001; Abdul-Wahab and Al-Alawi, 2002; Nunnari et al., 2004). The generation of sulphur dioxide (SO_2) from a heavily industrialized area with several petrochemical complexes may affect the surrounding environment. SO_2 is formed primarily from the combustion of sulphur-containing fuels and can affect the health of the people. The introduction of SO_2 standards created a need for method of modeling the dispersion of SO_2 to assist in identifying areas at risk of exceeding the standards, identifying measures that could be taken to meet the standards, and predicting the economic impact of control measures (World Health Organization, 1999; 2000).

A model widely used for estimating atmospheric concentrations of a chemical, downwind from a source, is the Steady State Gaussian Plume Model. There are numerous research works that involve in estimating pollutant concentrations downwind from a multiple source utilizing the Steady State Gaussian Plume Model at different study areas

(Zannetti, 1983; Al-Sudairawi et al., 1988; Ramesh and Naperkoski, 1984; Dhari and Yehia, 1996; Abdul-Wahab, 2002; Morgan, 2003; Sivacoumar, 2001; Joshua et al., 2005).

In this paper, SO_2 dispersion isopleths were develop for predicting maximum SO_2 levels emitted from Seberang Perai Industrial Area, Penang. The aim was to determine the accuracy of Steady State Gaussian Plume Model by verifying the predicted concentration values with onsite measurements for SO_2 within a factor of 2. The effects of variations for meteorological parameters and physical parameters in the model that are expected to affect the SO_2 concentrations were investigated. They were wind speed, atmospheric stability class, wind direction, mixing height, ambient temperature, stack exit velocity, stack exit temperature and emission rate.

1.1 The need for air dispersion modeling

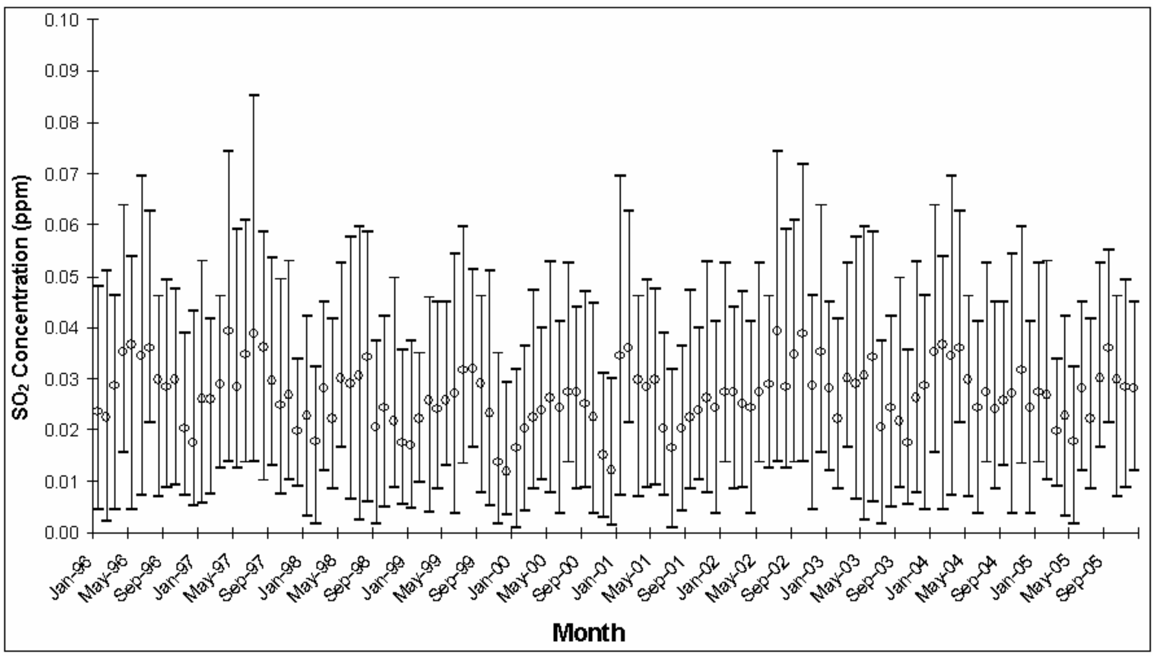
In establishing ambient air quality standards, regulations have been introduced in order to set limits on the emissions of pollutants (United State Environmental Protection Agency, 1999). To achieve these limits, consideration was given to mathematical and computer modeling of air pollution. Therefore, air quality models are indispensable tools for assessing the impact of air pollutants on human health and the urban environment (Gokhale and Khare, 2004). The necessity for such models has increased tremendously especially with the rising interest in the early warning systems in order to have the opportunity to take emergent and preventive actions to reduce pollutants when conditions that encourage high concentrations are predicted (Perez, 2001).

Air dispersion model is used to estimate the pollution concentrations attributable to a source or group of sources (World Health Organization, 2004; Minnesota Health State, 2004; United State Environmental Protection Agency, 2005). Air dispersion modeling can simulate a point and multiple source; a two-dimensional source (fugitive dust from a road that is wide and long); or a three-dimensional source (fugitive dust from a large coal pile that is wide, long and tall).

It is a way to mathematically simulate atmospheric conditions and behavior. It is usually performed using computer programs. Using inputs such as meteorological data and source emissions, air models can calculate pollutant concentrations in the air or the amount of pollutants deposited (deposition) on the ground. There are many kinds of air dispersion models, and an appropriate model is selected based on the type of analysis that is needed. Results of model simulation can predict the impacts of new sources before they are introduced and also allow an examination of the effects of different types of pollution controls before any actual changes are made to the sources of pollution. In addition, air dispersion modeling is sometimes used to locate air quality monitors in areas where high pollutant concentrations are most likely to occur. Besides, air pollution modeling can be used for stack design studies, combustion source permit applications, regulatory variance evaluation, monitoring network design and prevention of significant deterioration through planners and decision makers to estimate, for example; the increased risk of health problems in people who are exposed to different amounts of air pollutant. Hence, air dispersion modeling is necessary to provide timely provision for assessing downwind concentrations.

1.2 Problem statement

The need for air dispersion modeling has increased with increasing public concern on environmental problems (United State Environmental Protection Agency, 2000; World Health Organisation, 1999, 2000, 2004). This need is even more important in developing countries due to rapid urbanization as nations forged ahead to become industrialized. According to Environment Quality Report (2003) published by Department of Environment Malaysia, SO_2 remained the main pollutant of concern in the Seberang Perai area due to industrial activities in the vicinity (Figure 1).



Source: Department of Environment, 1996-2005

Figure 1: SO_2 concentration (ppm) at Seberang Perai Station from year 1996 until 2005